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Invention: AIR GAP WINDING METHOD AND SUPPORT STRUCTURE FOR A SUPERCONDUCTING GENERATOR AND METHOD FOR FORMING THE SAME

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SPECIFICATION

AIR GAP WINDING METHOD AND SUPPORT STRUCTURE FOR A SUPERCONDUCTING GENERATOR AND METHOD FOR FORMING THE SAME

This invention was made with government support under government contract no. DEFC0293CH10589 awarded by the Department of Energy. The government has certain rights to this invention.

BACKGROUND OF THE INVENTION

This invention relates to electric machines such as electric power generators and electric motors, and in particular to a stator winding support structure for use with a superconducting rotor.

In order to generate current, an electric generator typically includes a rotor and a stator, each of which contains a winding. The rotor is conventionally arranged within the stator to define an air gap therebetween. The stator conventionally includes a frame and a cylindrically-shaped core having magnetic teeth on its inner circumference. The teeth of the stator core form a plurality slots which receive the stator winding and therefore provide radial and tangential winding support. The teeth of the stator core also provide a grounding plane since the stator winding contacts the teeth. These teeth, however, are not desirable or needed when the rotor winding is formed by a superconducting winding that produces a very strong magnetic field. In the absence of the teeth, the stator winding is arranged within the magnetic field and thus produces both tangential and radial pulsating forces imposed on itself. While the tangential forces provide useful torque during normal operation, the radial forces produce an undesirable stator winding vibration.

Several attempts have been made in the past to produce a superconducting generator in the10/20 MVA size. Only limited success has been achieved, however, to support and hold a stator winding against the strong magnetic field produced by the superconducting rotor. This limited

success has resulted, for example, from a very complex helical armature or air gap windings requiring numerous complex spring and tie devices.

It would thus be beneficial to provide a support structure for a stator winding for use with a superconducting rotor which supports the air gap between the rotor and stator and which transmits the torque between the stator and rotor while preventing stator winding vibration. The support structure supports and holds the stator winding circumferentially and radially against the stator core. It would be further beneficial to provide the support structure with a minimum number of parts and a minimum amount of complexity and cost.

BRIEF SUMMARY OF THE INVENTION

~~In accordance with an exemplary embodiment of the present invention~~, a winding support structure for use with a superconducting rotor comprises an inner support ring, an outer support ring arranged around an outer circumference of the inner support ring, first and second support blocks coupled to said outer support ring and a lamination coupled to the first and second support blocks. A slot is defined between the support blocks and between the outer support ring and the lamination to receive a portion of a winding. The inner ring is a solid ring and the outer ring is a split ring. The outer ring expands to produce a radially outward force against the support blocks when the inner ring is moved axially with respect to the outer ring. The winding support structure may also comprise another inner support ring and another outer support ring which is arranged around the outer circumference of the another inner support ring and is coupled to the lamination. A clearance space in the slot is filled with a RTV. The winding structure may also comprise a third support block coupled to the outer support ring to define another slot between the second and third support blocks to receive another portion of the winding. The winding support structure transmits torque and ~~prevents stator winding vibration.~~

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~~In accordance with another exemplary embodiment of the present~~ invention, a method of forming a winding support structure for use with a superconducting rotor comprises providing a lamination, coupling first and second support blocks to the lamination, providing an inner support ring and an outer support ring around an outer circumference of the inner support ring, and coupling the lamination and the support blocks to the outer ring to define a slot between the support blocks and between the lamination and the outer ring to receive a portion of a winding. An RTV is applied into a clearance space in the slot. Wedges are respectively arranged between adjacent bars forming the winding prior to applying the RTV into the clearance space and then removed after applying the RTV into the clearance space. Additional RTV is applied in a space where the wedges are removed. Coupling the lamination and the support blocks to the outer support ring comprises pulling the winding to the outer support ring and tying the winding to the inner and outer support rings. Providing an inner support ring and an outer support ring comprises providing a solid ring and a split ring, respectively. The outer ring expands to produce a radially outward force against the support blocks when the inner ring is moved axially with respect to the outer ring. Another outer support ring can be provided around an outer circumference of another inner support ring and coupled to the lamination. A third support block may be coupled to the outer support ring to define another slot between the second and third support blocks to receive another portion of the winding. The method of forming the winding support is accomplished using a minimal number of parts and minimal construction cost.

In accordance with yet another exemplary embodiment of the present invention, an apparatus for use with a superconducting rotor comprises an inner support ring, an outer support ring arranged around an outer circumference of the inner support ring, first and second support blocks coupled to the outer support ring, a lamination coupled to the first and second support blocks, and a winding. A portion of the winding is arranged within a ~~slot that is defined between the support blocks and between the outer ring,~~

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~~and the lamination. The inner ring is a solid ring and the outer ring is a split ring. The outer ring expands to produce a radially outward force against the support blocks and the winding when the inner ring is moved axially with respect to the outer ring. A clearance space in the slot is filled with an RTV. The apparatus can further comprise another inner support ring and another outer support ring which is arranged around the another inner support ring and coupled to the lamination. The apparatus can further comprise a third support block coupled to the outer support ring to define another slot between the second and third support blocks and between the outer support ring and the lamination, another portion of the winding being arranged in the another slot.~~

BRIEF DESCRIPTION OF THE DRAWINGS

These, as well as other objects and advantages of this invention, will be more completely understood and appreciated by careful study of the following more detailed description of the presently preferred exemplary embodiments of the invention taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a top view of, inter alia, a winding support structure in accordance with an exemplary embodiment of the present invention;

FIGURE 2 is a cutaway view of, inter alia, a winding support structure shown if Figure 1;

FIGURE 3 is a cross-sectional view taken from line 3-3 in FIGURE 1;

FIGURE 4 is a partial cross-sectional view illustrating details of the winding support structure shown in Figure 1;

FIGURE 5 is a detailed partial cross sectional view illustrating details of the inner and outer support rings illustrated in FIGURE 4; and

FIGURE 6 is a partial cross-sectional view of, inter alia, a winding support structure which incorporates wedges during its construction in accordance with an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Figures 1-3 illustrate a winding support structure 1 in accordance with an exemplary embodiment of the present invention. The winding support structure 1 can be used, for example, in a 100 MVA or larger generator which includes a superconducting rotor (not shown) and a stator. The support structure 1 supports a stator winding 40 comprising a plurality of bars so that the support structure 1 transmits torque between the rotor and the stator of the generator and prevents stator winding vibration while in the presence of a strong magnetic field produced by the superconducting rotor. The bars of the winding 40 are formed, cooled, insulated and grounded in a conventional manner.

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~~The support structure 1 includes a plurality of inner support rings 10a-~~ 10j, a plurality of outer support rings 20a-20j, a plurality of laminations 30a-30i, 31a-31i, a plurality of support blocks 51a-51l and an RTV 42. The inner support rings 10a-10j are centered about a longitudinal axis 3 of the support structure 1 and are spaced axially apart along the direction of the longitudinal axis 3. The outer support rings 20a-20j are respectively arranged around the outer circumferences of the inner support rings 10a-10j. Each one of the laminations 30a-30i to 31a-31i forms a semi-circle portion and a pair of laminations (e.g., 30a, 31a) together forms a complete circumference of the support structure 1. Those skilled in the art will appreciate that the complete circumferences can be formed by dividing the laminations into more than two semi-circle portions. The laminations 30b-30i and 31b-31i are stacked in the ~~axial direction (i.e., along the direction parallel to the longitudinal axis 3) with~~

~~respect to laminations 30a, 31a, respectively, to form a core of the stator.~~ Gaps 33 are interposed between each of the laminations 30a-31i, 31a-31i in the axial direction to allow for air cooling of the winding 40. Alternatively, a cooling pad (not shown) such as a water cooling pad can be interposed between each of the laminations 30a-30i, 31a-31i in the axial direction. While the discussion below focuses primarily on only one inner support ring 10a, one outer support ring 20a, one laminations 30a, and two support blocks 51a-51b in detail, those skilled in the art will appreciate that similar comments ~~apply to the others forming the support structure 1.~~

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Referring now to Figure 4, the lamination 30a has a plurality of square or rectangular-shaped notches formed (e.g., punched) in its inner periphery. The size of the notches are such that first and second support blocks 51a, 51b of the plurality of support blocks 51a-51l are each tightly engaged and held in respective notches. Specifically, an end of each of the support blocks 51a, 51b which is radially furthest from the axis 3 (see Fig. 1) is engaged into respective notches of the lamination 30a with a close fit. The lamination 30a is thus a "toothless" lamination to the extent that it does not include a magnetic teeth which are, for example, integral with the lamination 30a. The support blocks 51a, 51b are preferably formed by a G11 or similar epoxy glass.

Some of the bars of the winding 40, preferably forming a single layer, are then inserted into a slot 70a which is defined between the first and second support blocks 51a, 51b. In the exemplary embodiment illustrated in Fig. 4, six bars of the winding 40 are inserted into the slot 70a defined between the first and second support blocks 51a, 51b. The space in the slot 70a between the support blocks 51a, 51b has dimensions such that a clearance space can be defined in the slot 70a between each of the bars of the winding 40, between each of the support blocks 51a, 51b and the bar positioned closest thereto, and between the bars and the lamination 30a.

The inner and outer support rings 10a, 20a are designed to be able withstand the radial inward forces imposed, for example, by the weight of laminations 30a, 31a. The inner and outer support rings 10a, 20a are both preferably made of a filament wound epoxy glass. The inner support ring 10a is a solid ring. The outer support ring 20a has an expansion gap 21 and thus forms a split ring. The support rings 10a, 20a effectively form a two piece fitted incline plane (see Fig. 5) so that when the inner (solid) support ring 10a is moved axially with respect to the outer (split) support ring 20a, the outer ring 10a expands via the expansion gap 21 to produce a radially outward force against the winding 40, laminations 30a, 31a and the support blocks 51a-51h.

During construction of the support structure 1, the support rings 10a, 20a are arranged in the bore of the stator. The winding 40 is then pulled radially inward and securely tied to the support rings 10a, 20b using a roving glass tie (not shown). Specifically, the roving glass tie is arranged around each bar of the winding 40 to cinch the bars to the outer support ring 20. When the construction is completed, the ends of the bars of winding 40 which are closest to the longitudinal axis 3 contact the outer support ring 20a. The ends of the first and second support blocks 51a, 51b which are radially closest to the longitudinal axis 3 (i.e., those ends of the support blocks 51a, 51b which are not engaged in respective notches of the lamination 30a) also contact the outer support ring 20a. The slot 70a defined between the first and second support blocks 51a, 51b in the circumferential direction is thus also defined between the outer support ring 20a and the lamination 30a in the radial direction.

Referring now to Figs. 1 and 4, the winding support structure 1 further includes a glass support block 51c of the plurality of support blocks 51a-51l. Like the other support blocks 51a-51b, 51d-51l, the third support block 51c is preferably formed by a G11 or similar epoxy glass. The third support block 51c is engaged at one end in a notch of the lamination 30a and contacts the

outer support ring 20a at the other end (i.e., the end radially closest to the longitudinal axis 3). Another slot 70b is thus formed between the second and third support blocks 51b, 51c in the circumferential direction and between the outer support ring 20a and the lamination 30a in the radial direction. The another slot 70b encloses another six bars of the winding 40a. As those skilled in the art will appreciate, additional slots can be formed in a similar manner. Again, similar comments of the foregoing description apply to all other laminations, inner and outer support rings and support blocks, slots, etc. forming the support structure.

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~~As noted above, clearance space is formed in the slot 70a of the~~ lamination 30a between the support blocks 51a, 51b. This clearance space exists, for example, between the bars of the winding 40, between each support block 51a, 51b and the closest bar of the winding 40, and between the bars and a face of the lamination 30a defining the slot 70a. In order to restrict the movement of the winding 40 caused by the electromagnetic forces of the generator and to ensure that the winding 40 electrically contacts the lamination 30a, the clearance space is filled by a high conductivity, high compression RTV 42.

As illustrated in Figure 6, prior to filling the clearance space in the slot 70a with a RTV 42, at least one teflon wedge 72a is placed on the inside diameter between two bars of the winding 40 to contain the RTV 42. Additionally, at least one teflon wedge 72b is arranged on the outside diameter between two bars of the winding 40. After the RTV 42 is applied to fill the clearance space, the wedges 72a, 72b are removed and additional RTV 42 is applied to fill the void formed where the wedges 72a, 72b are removed. The RTV 42 can be applied into the clearance space through radial tubes (not shown) spaced around the circumference of the stator core which allow the injection of the RTV 42. Cooling pads similar to those disclosed in the commonly assigned U.S. Patent 5,473,207 (Hopeck et al, "Cooling Pads ~~for Water-Cooled Stator Cores in Dynamoelectric Machines and Methods of~~

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~~Fabrication"), the contents of which are incorporated herein by reference, can~~ also be provided on the outer circumference ~~of the~~ stator core and have ~~provisions for the addition of the radial tubes for RTV injection~~.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.